

# Analysis of single- and double-threaded rolling for production of grinding balls of alloy steel grades

**I Galimyanov**

Engineering office JSC EVRAZ NTMK, 1, ul. Metallurgov, Nizhny Tagil, 622025, Russia

E-mail: Ilyas.Galimyanov@evraz.com

**Abstract.** JSC EVRAZ NTMK has mastered the technology of production of grinding balls with high hardness of surface and normalized hardness at the depth of 0.5 of a ball radius (4th hardness group) and normalized volume hardness (5th grade hardness) in accordance with Russian state standard GOST 7524–2015. Currently rolling of balls with the rated diameter of 100 mm is performed using double-threaded rolls. Single-threaded pass design is used for rolling of the 120-mm grinding balls. Double-threaded pass design increases a feed angle of rolls. The higher angle increases tangential stresses. 100-mm balls produced through the double-threaded pass design where the flanges excessively wear, show specific defects on a surface of the balls. This article describes the materials and results of the study of rolling of the grinding balls with the diameter of 100 mm and 120 mm produced via single- and double-threaded designs. Lower tangential loads applied to the balls during single-threaded rolling affects their macro structure, their hardening layer thickness.

## 1. Introduction

The main consumers of the grinding balls are domestic and foreign mining and processing combines (Ukraine, Kazakhstan, Poland, Mongolia, etc.). Many domestic and foreign consumers doing processing of hard ores of non-ferrous metals demand high strength, hardness and wear resistance of the grinding balls [1].

For this purpose, JSC EVRAZ NTMK has mastered the technology of production of grinding balls with high hardness of surface and normalized hardness at the depth of 0.5 of a ball radius (4th grade hardness) and normalized volume hardness (5th grade hardness) in accordance with [2].

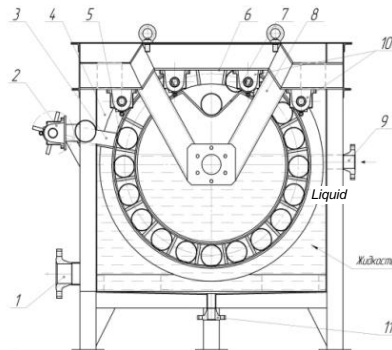
For this purpose, a grinding ball plant has been commissioned. The plant includes: feedstock storage area; charging area; re-heating furnaces area; mill area; balls hardening area; tempering area (stress relieving); finished products shipment and storage area; change parts preparation area; water treatment and cooling system. A walking hearth re-heating furnace is divided along the length into continuous, heating and soaking zones. Cross ball rolling mill. Rolls with the gaged variable pitch screw thread are the working tool of SPSH 60 to 120.

The balls hardening area is intended for heat treatment of the balls with the rated diameter of 60, 70, 80, 90, 100, 110 and 120 mm, of hardness category 1–5 provided that tempering is done in a tempering furnace. An equipment set of the balls hardening section includes a hardening tank, a hardening drum, a driving station and an input chute.

In terms of structure, the hardening drum constitutes a central frame on which twenty-four through pipes are fixed along the circumference of the circle, with screw augers, having a screw line direction



opposite to the drum rotation, installed inside (Figure 1). Tempering area (stress relieving). The tempering furnace is a conveyor furnace with circulatory atmosphere of direct convective heating.



**Figure 1.** Structure main elements: 1 – fluid removal; 2 – dosing mechanism; 3 – input chute; 4 – container; 5 – external stationary part of drum; 6 – moving part of drum; 7 – internal moving part of drum; 8 – ball; 9 – fluid feed line; 10 – roll; 11 – fluid drainage.

## 2. Methods

Rolling of the balls from billets of different accuracy level, keeping or removing a web in a gorge requires rolls of different pass designs. A screw gage for the balls rolling consists of two sections that are the forming one and finishing one [2]. The forming section provides bite of a billet and its gradual reduction into a ball connected to the billet body via the web. The forming is performed by the flanges having a constantly increasing height, by which a diameter of the web is changed. A metal displaced from the webs into the ball provides radial deformation and increase of a ball diameter compared to a feedstock diameter. Therefore, the feedstock diameter is 1 to 2 mm smaller than that of a ball [4]. Correction of groove filling may be performed by adjusting the feed angle of the rolls  $\alpha$ , which is normally 2 to 4° at the ball-rolling mills. A groove length (number of turns) is measured in degrees of the flat groove screw line. If the groove total length is 900–1350°, the forming section takes 360–540°, and a sizing section, at which diameters of billets are aligned prior to forming and an elongated finishing section, takes up to 810°. When rolling the balls of bearings, only sizing of the ball is performed at the finishing section [5]. This section has a constant pitch and a threading profile corresponding to a profile of a ball being rolled, as well as a constant angle of threading rise equal to the feed angle of rolls  $\alpha$ . One ball is rolled in one revolution of the rolls [6, 7].

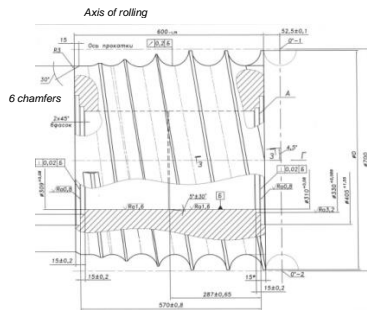
When rolling the grinding balls, a roll is distinguished by the presence of the sizing section aligning the diameters of the billets prior to forming and the elongated finishing section (up to 810°). A small axial displacement of the rolls breaks off the web at the beginning of the finishing section, and then rotates the ball along the axis perpendicular to a rolling axis, the flanges cut off the webs and the vertex projections are rolled smooth [8, 11]. To increase the production output of the mill, double- and triple- threaded screw grooves are used along with the single- threaded ones, which allows getting 2–3 balls for one revolution of the rolls. The average production output of mills is 1–6 balls per second, up to 50–60 million of units/year (10–150 ths. tons/year) [9].

Forming of products during transverse rolling in the screw grooves is carried out by gradual reduction of a rotating feedstock. An allowable value of a single reduction for half a revolution of the feedstock is determined by conditions of its bite by the rolls [10]. Thus, to ensure the bite of the feedstock by the rolls, the reduction shall not exceed the allowable value.

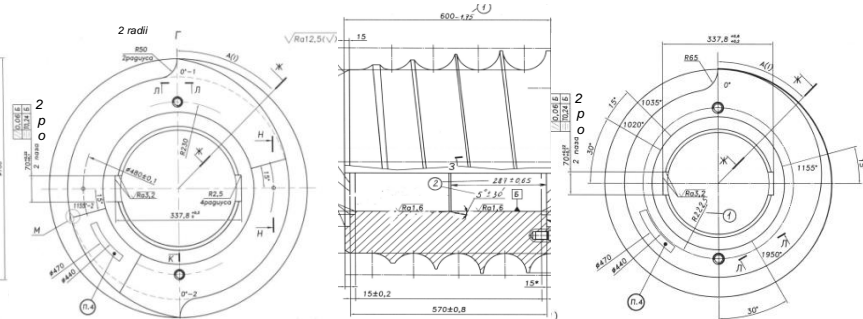
As the operating experience shows, in addition to the single bite, loosening of the metal during the transverse rolling in the screw grooves is affected by: width of the groove flange, tension of the metal in a part of the feedstock being reduced, temperature of the rolling, rotation speed of the rolls, difficulty in an axial metal flow and the presence of an excess metal in the groove.

Currently rolling of the balls with the rated diameter of 100 mm is performed using the double-threaded rolls (Figure 2). Rolling of the grinding balls with the diameter of 120 mm is performed using the single-threaded design (Figure 3). The feed angle of the rolls is 4.5–5°, since it is equal to an average angle of inclination of the flanges, due to application of the double- threaded design in the process of rolling of the balls [11]. With the pitch of 227.387 (for the two- thread design) and the roll

diameter of 700 mm, the theoretical angle is  $B = 5.7^\circ$  (Table 1). When working with such angles, the tangential stresses increase due to an increase in the feed angle (Figure 4) [12].



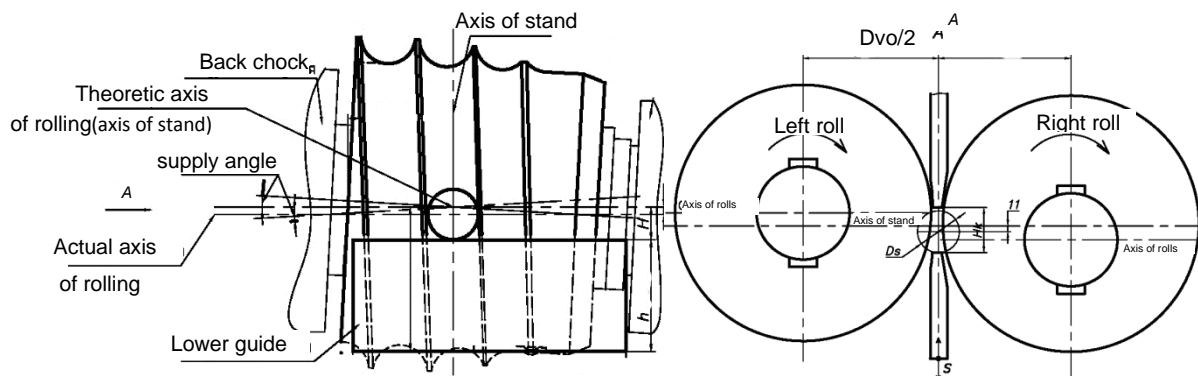
**Figure 2.** Roll with double- threaded design for rolling of the balls with the diameter of 100 mm.



**Figure 3.** Roll with single- threaded design for rolling of the balls with the diameter of 120 mm.

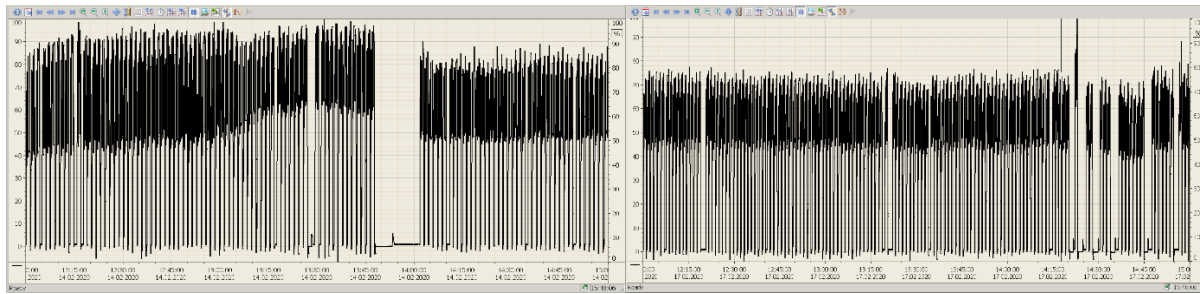
**Table 1.** The estimated parameters.

RPD	Diameter of the cold ball (nom.), mm	Design distances from the roll axis to the rolling axis $D_v$ (parallel rolls), mm	MIN-output		Distance between the roll flanges in the gorge, mm	K, mm	Feed angle, $\alpha^\circ$ , deg.
			Nominal value	Cut			
$\varnothing 120$ single-threaded	124.8	700	698.0	694.5	17.7	13 (10.3 %)	2.5–3.5
$\varnothing 100$ double-threaded	104.0	700	698.0	694.5	13.0	10 (9.5 %)	4–5



**Figure 4.** Location of rolls during setup.

When reprofiling, a ratio of the pitch to the diameter of the roll increases even more, which pass to the greatest tangential loads, which reduce the efficiency of useful forces during rolling. All this pass to an increase in loads necessary for the formation of the ball, and consequently to an increase in load on the rolling motor. In this regard, when rolling the ball with the diameter of 100 mm with a standard hourly production output, the loads on the rolling motor are at the average of 85–90 % of the nominal loads, and, for example, when rolling the ball with the diameter of 120 mm with an hourly production output, the loads on the rolling motor are 70–75 % from the nominal ones (Figure 5, 6). In addition, when the tangential loads are increased, distribution of a contact pressure is moved from the top of the flange to a side surface, which leads to intensive wear of the rolls.



**Figure 5.** Rolling motor loads during rolling of 100 mm ball.

**Figure 6.** Rolling motor loads during rolling of 120 mm ball.

During the double-pass rolling of the grinding balls with the diameter of 100 mm, the large feed angle of the rolls causes increased wear of the flanges not only in the normal (perpendicularly to the roll axis – along the tops of the flanges), but also in the tangential (lengthwise the roll axis – along the side of the flanges) directions (Figure 7). This factor significantly reduces the consumption rate of the rolls.



**Figure 7.** The roll wear at the ball web break area.

**Figure 8.** The grinding balls with the diameter of 100 mm affected by roll flange wear.

Production of the balls with the diameter of 100 mm on the rolls with the double- threaded design with excessive wear of the flanges causes unique defects on a surface of the balls, and dimensions of these defects may exceed maximum allowable deviations (Figure 8).

During the single- threaded rolling of the balls with the diameter of 120 mm, the smaller feed angle of the rolls causes decrease of wear of the flanges and the consumption rate of the rolls respectively.

Currently the possibility of production of the balls with the rated diameter of 100 mm on single-threaded rolls is considered, an increase of durability of the rolls is planned respectively.

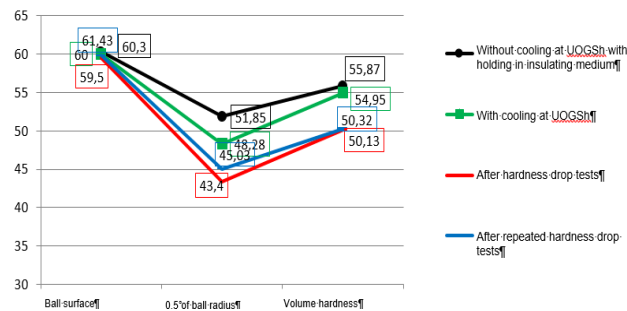
### 3. Results

For this purpose, it is required to order development of design and manufacture a set of rollers and blocks. When comparing the methods of single- threaded and double- threaded rolling of the balls, the following factors are revealed:

- When using the single- threaded design, the feed angle will be reduced by 2 times, which will pass to a decrease in the tangential loads.
- During the single- threaded design of the forming section, the feedstock will be reduced in 3 full roll revolutions instead of 1.5 revolutions on a current design, which will pass to more gentle reduction regimes and allow reducing the load on the rolling motor and decreasing wear of the rolls.
- Decreasing the load on the rolling motor, as well as reducing an angle of spindles to 2.5 degrees, will reduce the total engine torque by 2 times, which will allow increasing a number of revolutions from 40 rpm currently used to 80 rpm and will keep the machine production output at the level of 80 balls per minute for the single- threaded design in general.

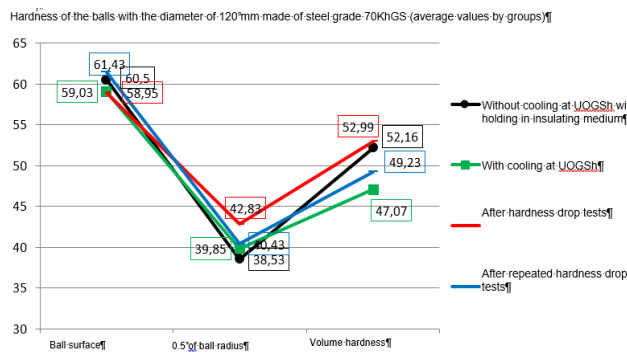
Reduction of the tangential stresses on the balls with the diameter of 100 mm during transfer to the single-threaded design influences on the macro structure, the value of hardening layer and hardness of balls (Figure 9). Reduction of the tangential stresses shall decrease a risk of crack of the balls [13].

Hardness of the ball with the diameter of 100 mm made of steel grade 70KhGS (average values by groups)



**Figure 9.** Hardness and the micro structure of the balls with the diameter of 100 mm made of steel grade 70KhGS.

Unacceptable defects and stress cracks were not detected in the course of control of the micro structure of the grinding balls with the diameter of 120 mm made of steel grade 70KhGS (Figure 10). The depth of the hardened layer was 18–31 mm.



**Figure 10.** Hardness and the micro structure of the balls with the diameter of 120 mm made of steel grade 70KhGS.

According to the results of certification of the grinding balls, compliance with the technical requirements of the 5th hardness group according to [2] was confirmed.

Subject to agreement, pilot batches were sent to the consumer PJSC Polyus to test the use of the grinding balls during grinding of non-ferrous metal ores. The grinding balls were loaded into ball crushers in cooperation with specialists of JSC EVRAZ NTMK. According to the results of using the grinding balls of the 5th hardness group according to [2], the consumer received improved results on specific consumption rate of the balls and increased the scope of supply.

#### 4. Conclusions

1. When rolling the ball with the diameter of 100 mm with the standard hourly production output (19.5 t/h), during the double-threaded rolling, the loads on the rolling motor are at the average of 85–90 % of the nominal loads, and, for example, when rolling the ball with the diameter of 120 mm with the hourly production output (22.1 t/h), during the single-threaded rolling, the loads on the rolling motor are 70-75% from the nominal ones.

2. Reduction of the tangential stresses on the balls with the diameter of 100 mm during transfer to the single-threaded design influences on the macro structure, the value of hardening layer and hardness of balls.

3. Decreasing the load on the rolling motor, as well as reducing an angle of spindles to 2.5 degrees, will reduce the total engine torque by 2 times, which will allow increasing the number of revolutions from 40 rpm currently used to 80 rpm and will keep the machine production output at the level of 80 balls per minute for the single- threaded design in general.

4. By means of innovative developments, the composition of advanced equipment allows achieving a stable technological process for producing the grinding balls that meet the technical requirements of the 5th hardness group according to [2].

5. JSC EVRAZ NTMK commissioned a unique grinding ball plant. The technology of industrial production of balls with the diameter from 60 mm to 120 mm with high hardness of surface and normalized hardness at the depth of 0.5 of a ball radius (4th hardness group) and normalized volume hardness (5th hardness group) as per [2], has been developed.

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